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Identifying Scatter Targets in 2D Space using In Situ Phased-Arrays for Guided Wave Structural Health Monitoring

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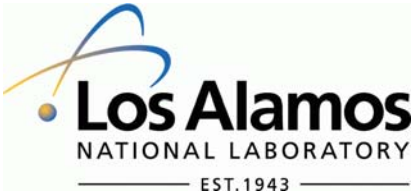
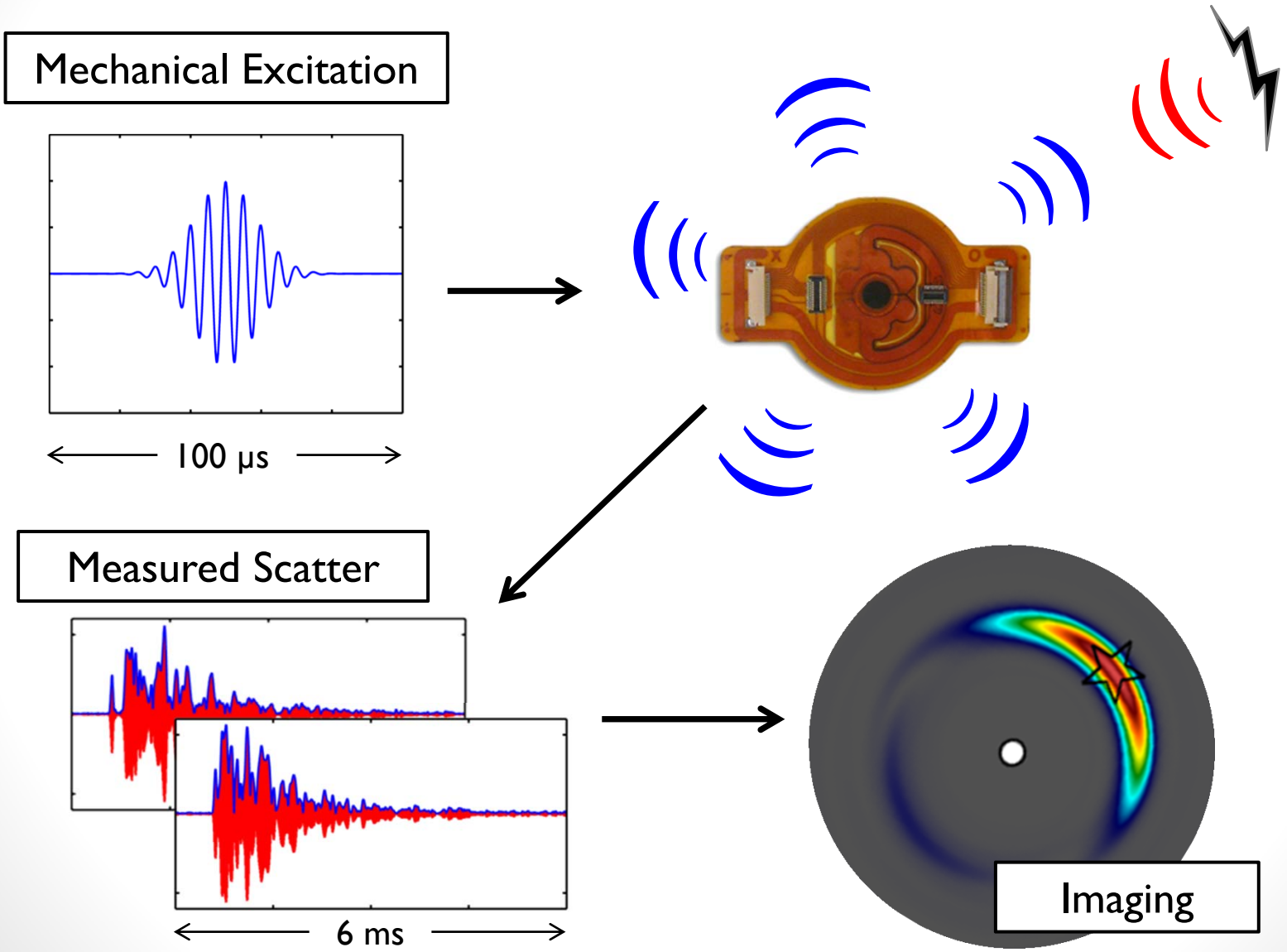


Guided Wave SHM

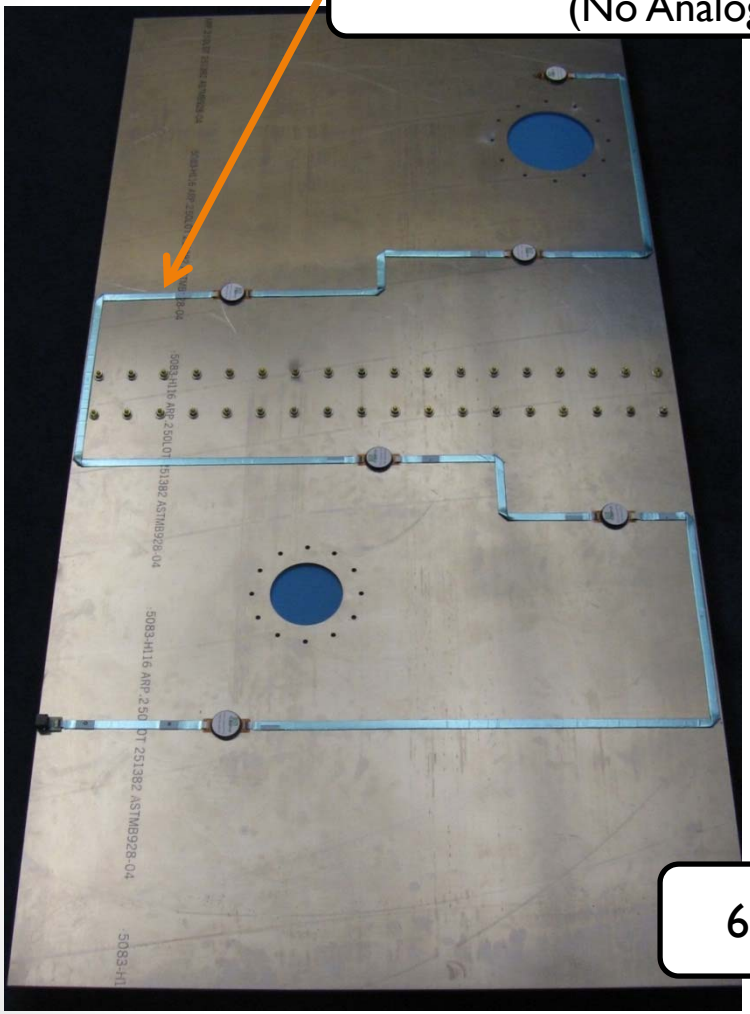


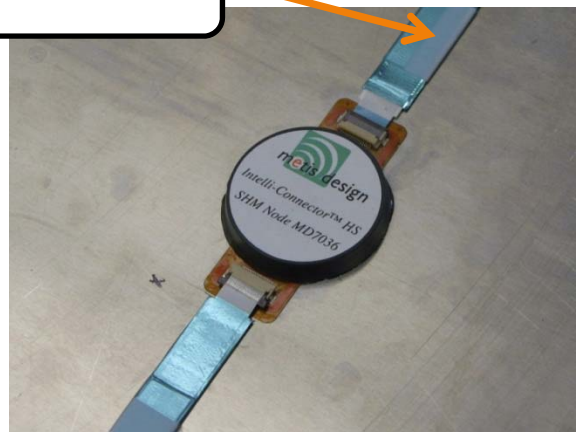
Outline

- Sensor Hardware
- Review of Time Domain Processing
- Review of Spatial Domain Processing
- The problem of multi-damage
- Target Identification
- Proof on Concept
- Conclusions

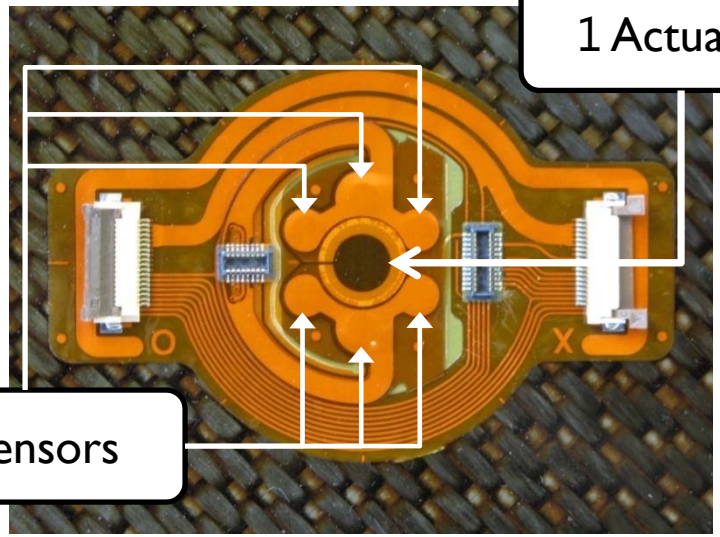
Sensor Hardware (MD7)

All-Digital Communications Line
(No Analog)





1 Actuator



6 Sensors

Time Domain Processing

- Filter
- Complex Envelope

Center Excitation Frequency

$$y_{CE}(t) = y_A(t)\exp(-j2\pi f_C t)$$

Analytic Signal

- Downsample
- Whiten

Mean

$$\boldsymbol{y}_W = (\boldsymbol{y}_{CE} - \boldsymbol{\mu})^H \boldsymbol{C}^{-1}$$

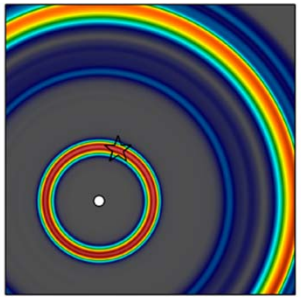
Covariance

- Transform to Spatial Domain (Time → Propagation Distance)

Spatial Domain Processing

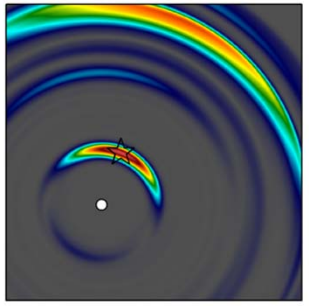
- Incoherent Beamforming

$$I^{(\mathrm{I})}(\boldsymbol{x}) = \sum_{m=1}^{M} a_m^{(\mathrm{I})}(\boldsymbol{x}) \left| w_m\left(d_m(\boldsymbol{x})\right) \right|$$



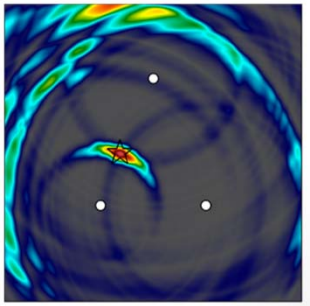
- Coherent Beamforming

$$I^{(\mathrm{C})}(\boldsymbol{x}) = \left| \sum_{m=1}^{M} a_m^{(\mathrm{C})}(\boldsymbol{x}) w_m\left(d_m(\boldsymbol{x})\right) \right|$$



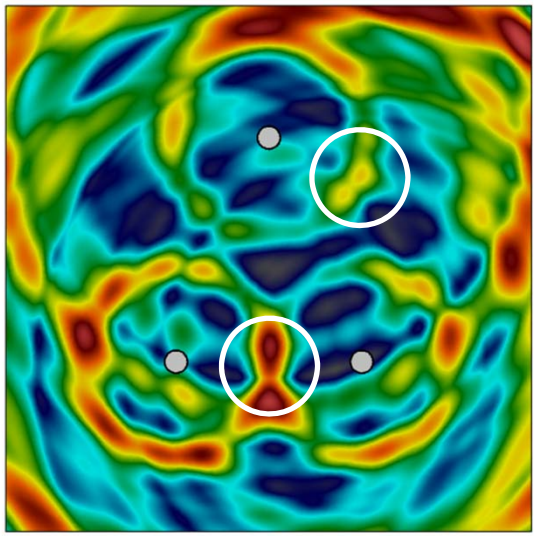
- Hybrid Beamforming

$$I^{(\mathrm{H})}(\boldsymbol{x}) = \sum_{n=1}^{N} a_n^{(\mathrm{I})}(\boldsymbol{x}) \left| \sum_{m=1}^{6} a_m^{(\mathrm{C})}(\boldsymbol{x}) w_{nm}\left(d_{nm}(\boldsymbol{x})\right) \right|$$

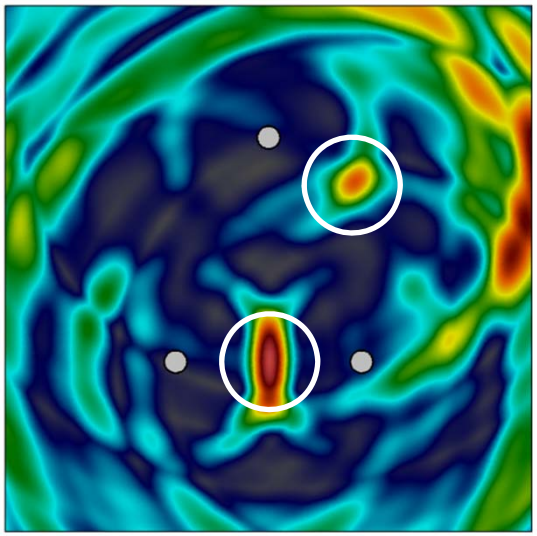


The Multi-Damage Problem

Incoherent



Hybrid

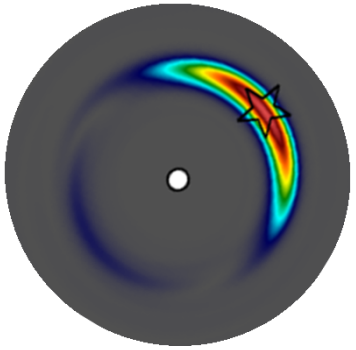


Target ID: Matching Pursuit

Decompose ultrasonic scan into sum of wave reflection packets

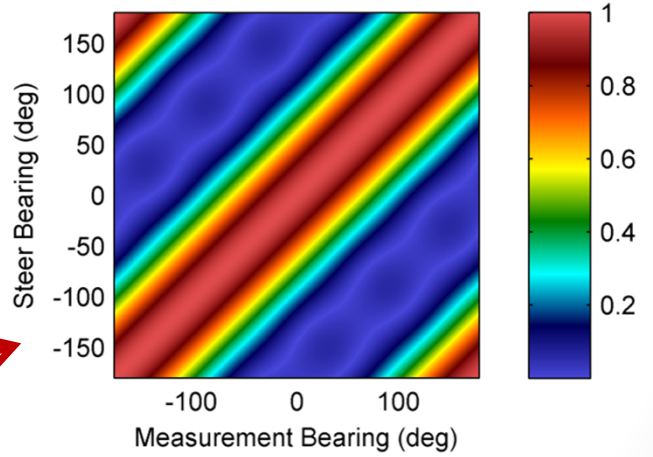
Target Amplitude Target Range Target Bearing

$$I^*(r,\theta) = \sum_i A_i K(r - R_i, \theta, \vartheta_i)$$



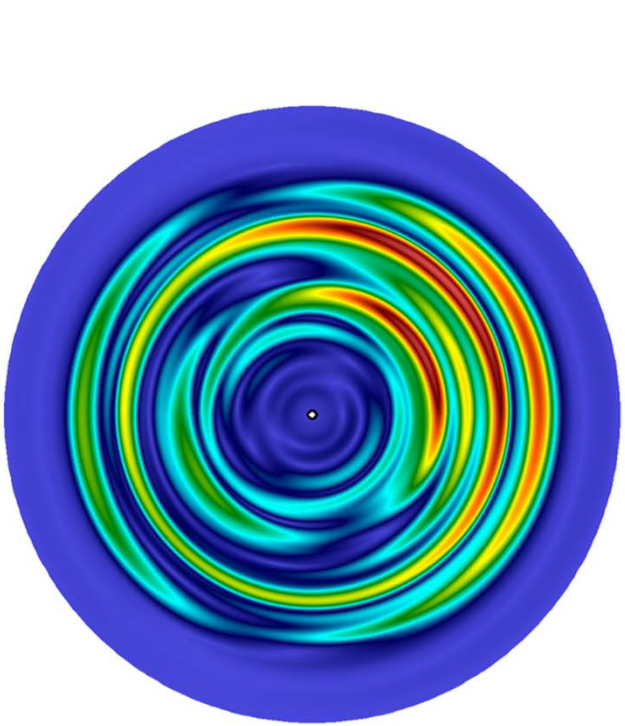
$$K(r,\theta,\vartheta_i) = \exp\left(\frac{-r^2}{2\sigma^2}\right) B(\theta,\vartheta_i)$$

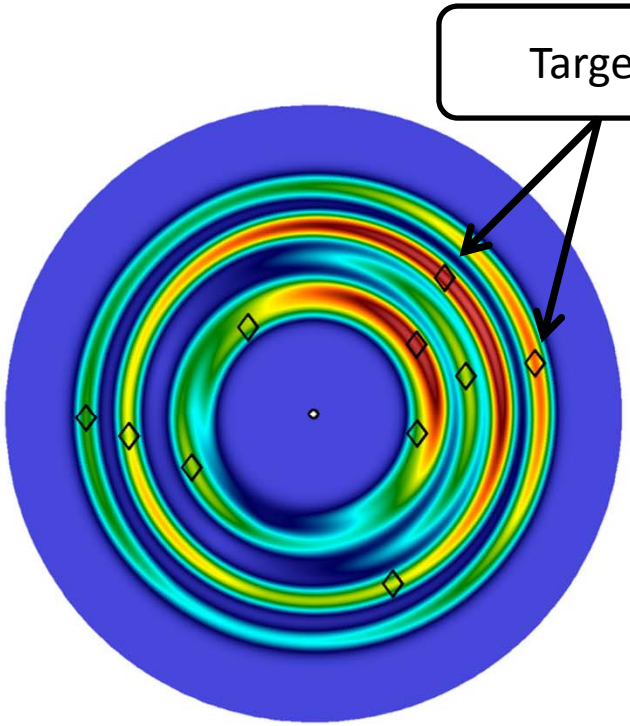
Pulse Width Beamshape



Parameters determined through Greedy Algorithm

Reconstruction Example



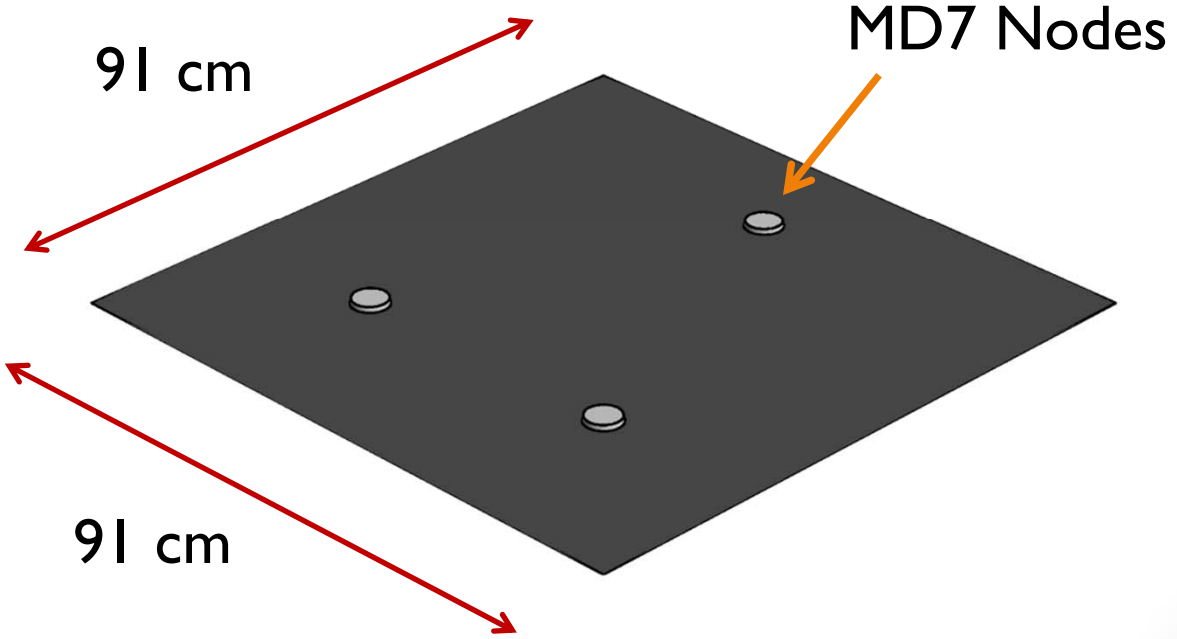


Why Identify Targets?

- Easier to identify individual sources of scatter
- Impossible targets can be surgically removed
- Secondary echoes can be reduced/eliminated through matched filtering
- Greatly reduced communications and storage requirements

Simple Experiments

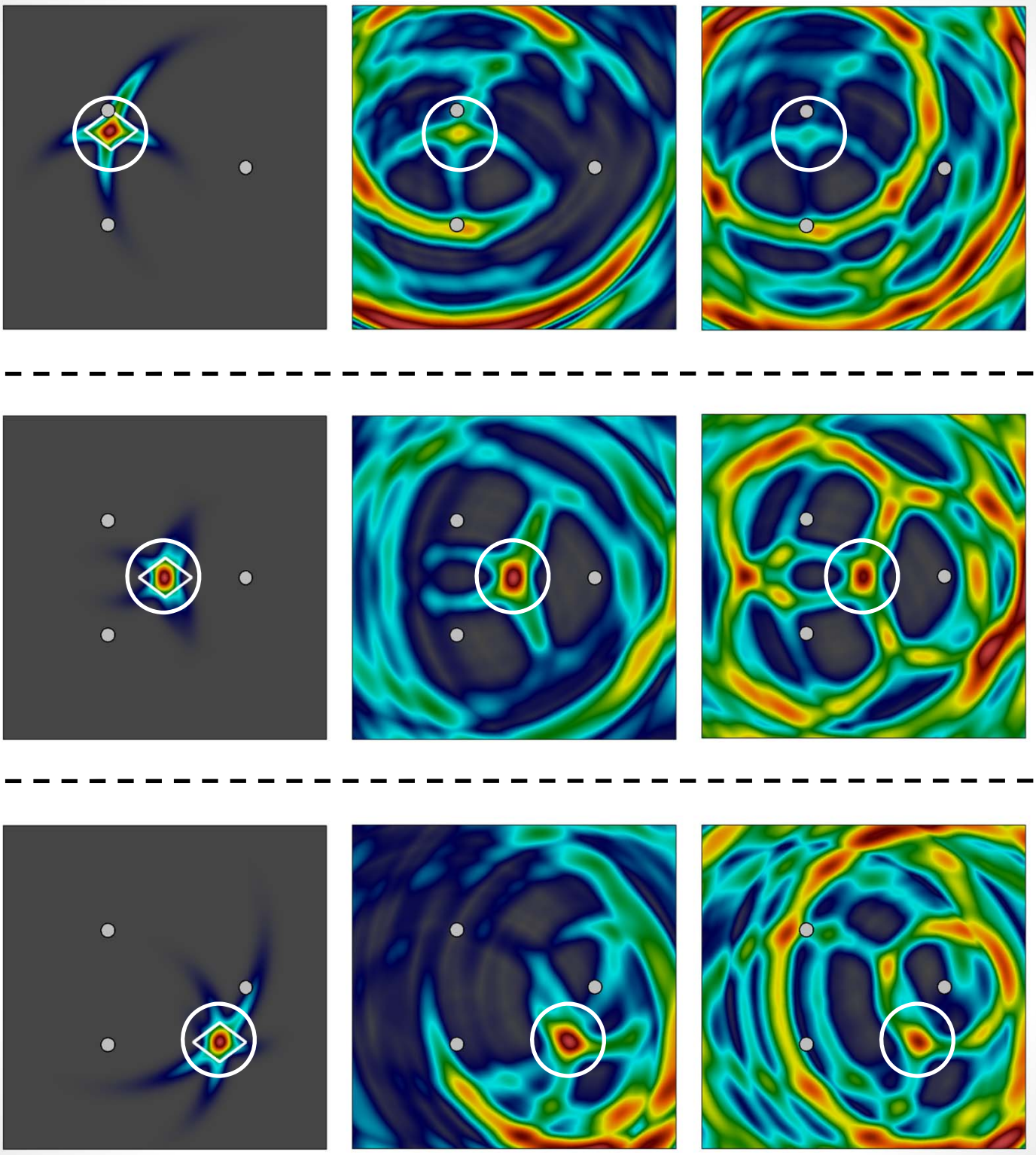
- 3mm Aluminum Plate
- 3 MD7 Nodes
- 50 KHz Excitation
- "Damage" – 10mm Disc Magnets

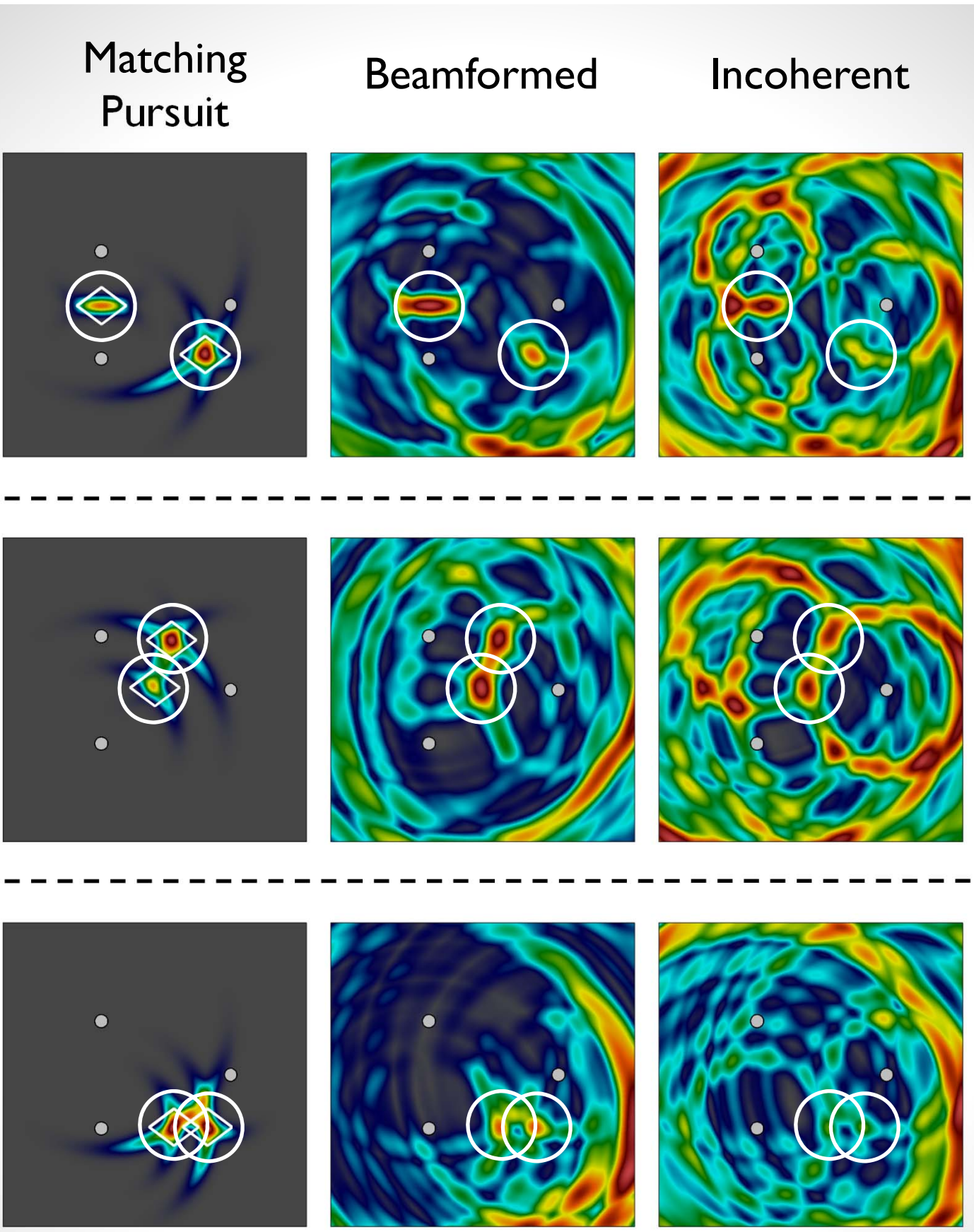


Matching Pursuit

Beamformed

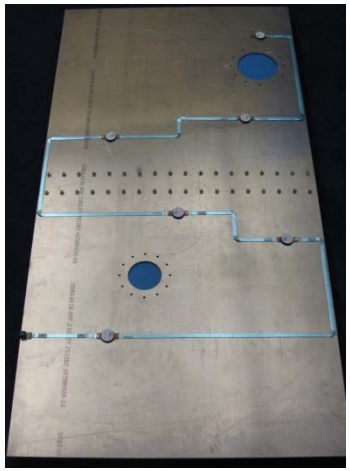
Incoherent

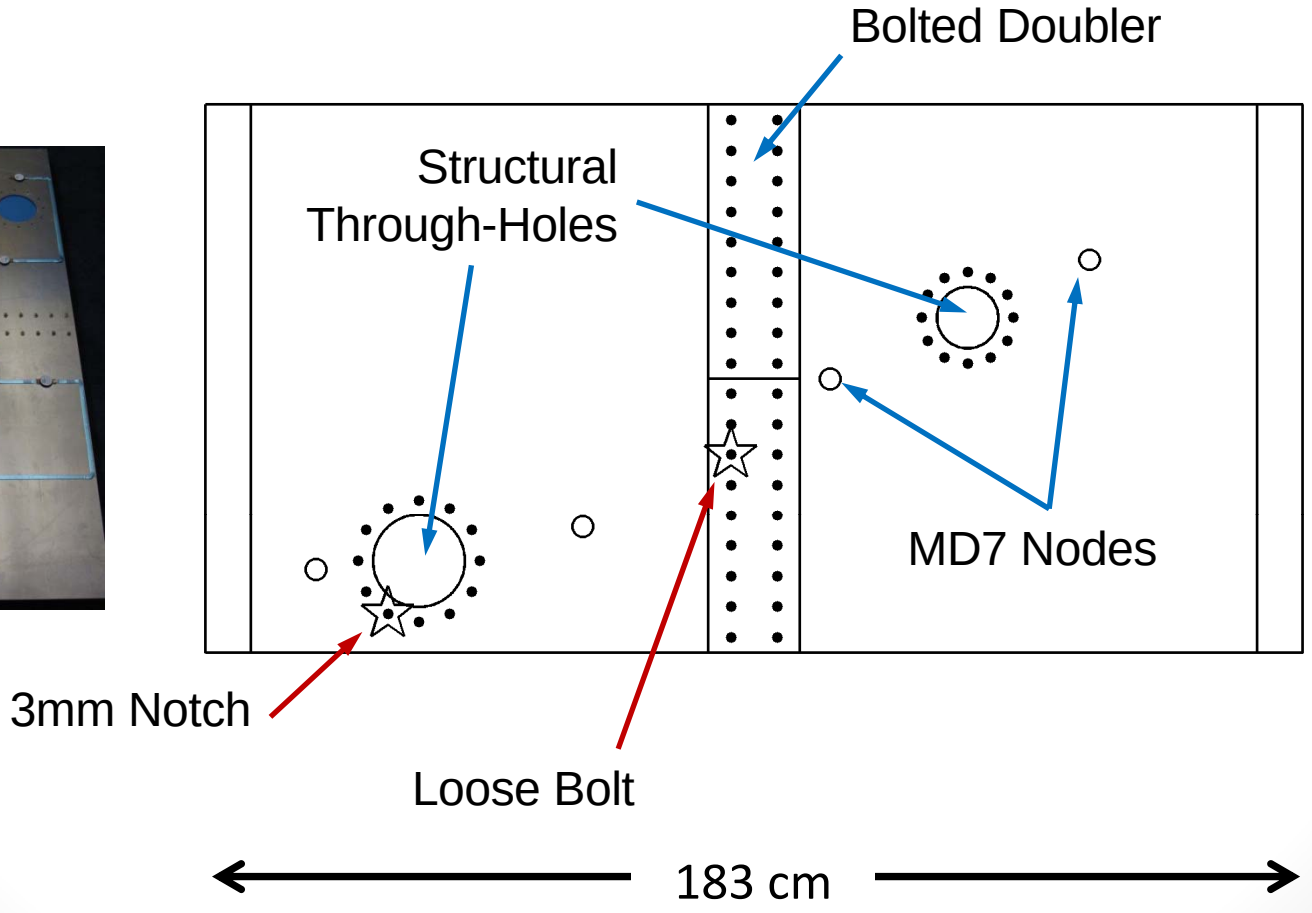



Matching Pursuit
Beamformed
Incoherent

Advanced Experimental Setup

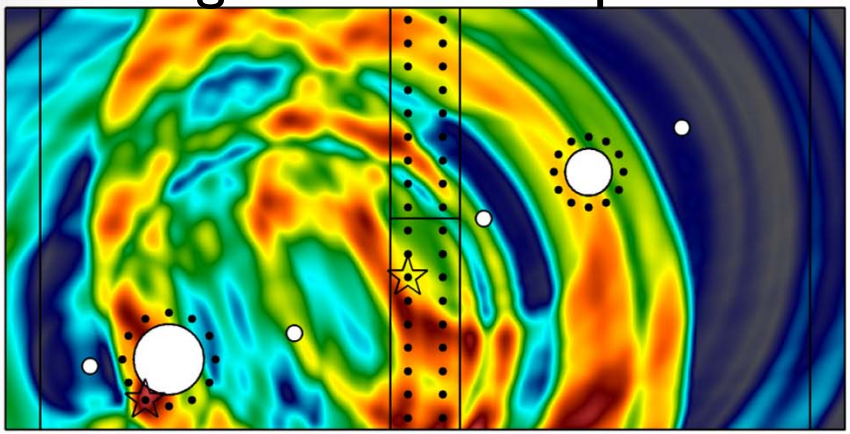
- **6 mm Aluminum Plate**
- **4 MD7 Nodes**
- **Test conducted at Metis Design, Cambridge, MA**
- **60 kHz Excitation**



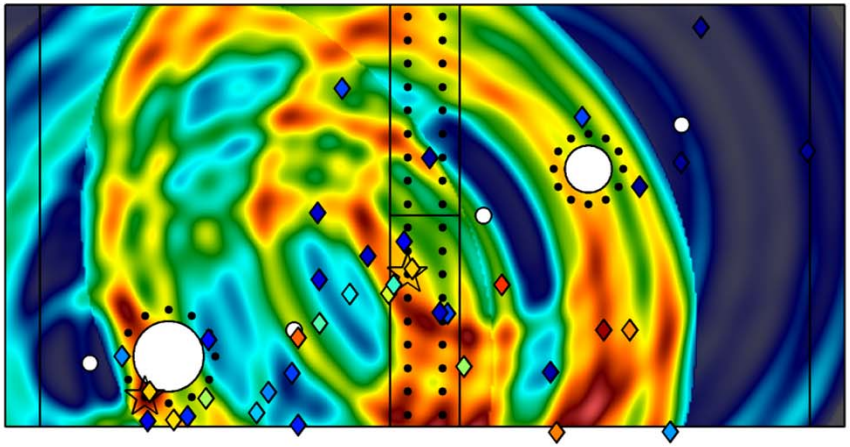


Results

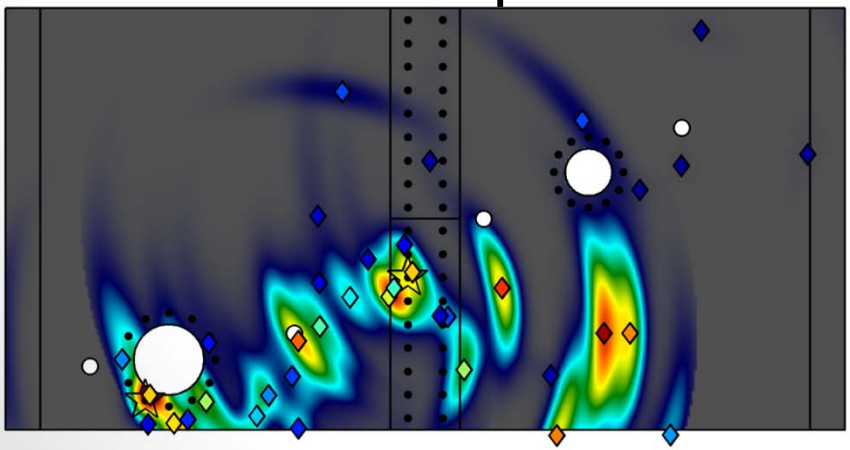
Original Scan Composite



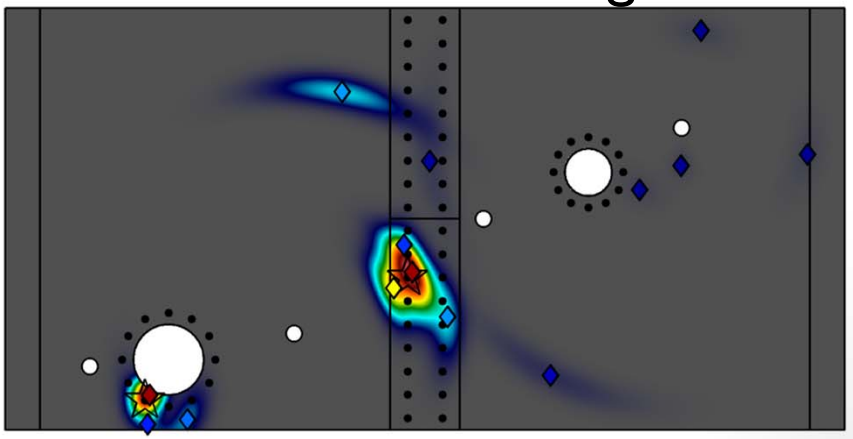
Reconstructed



Alternative Shape Function



Matched Filtering



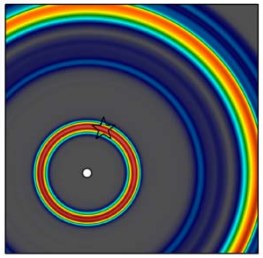
Comments

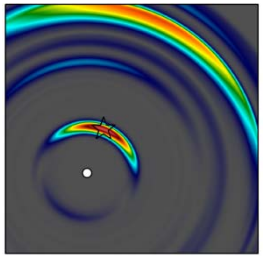
- Just a proof on concept
  - Verification through statistical analysis is necessary
- Operating in the spatial domain seems more robust
- So far only applies to phased arrays
  - Images using single transducer pairs have ambiguous target locations
- Room for more advanced algorithms: Clustering

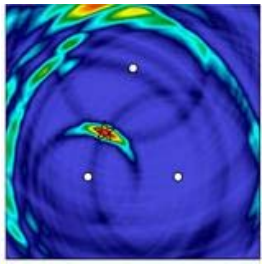
Acknowledgements

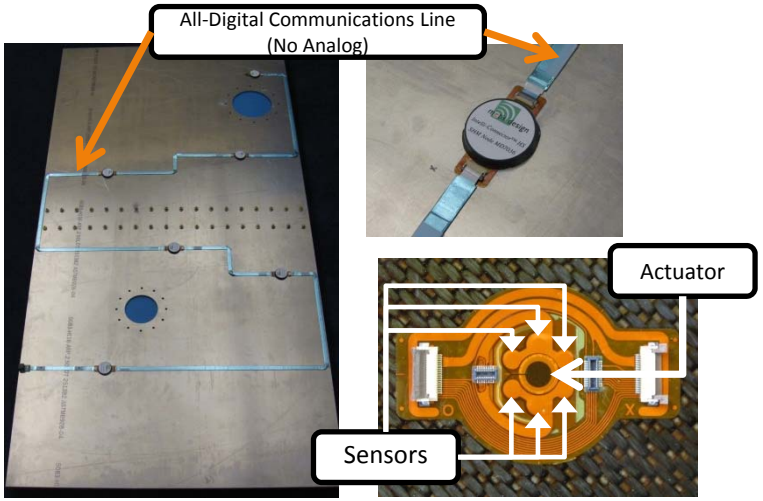
This work was primary supported through a **Small Business and Technology Transfer (STTR)** grant sponsored by the **Office of Naval Research (ONR)** and under the direction of Dr. Ignacio Perez .

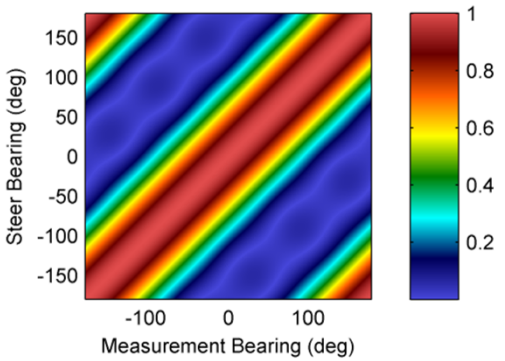
Summary

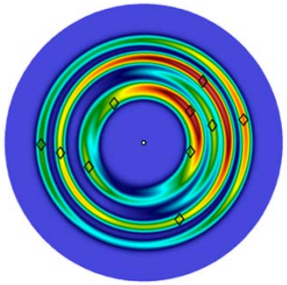












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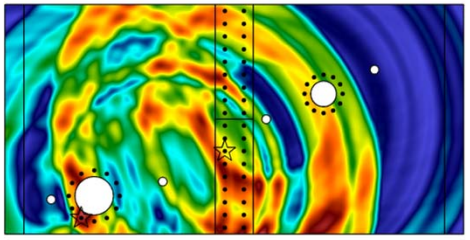
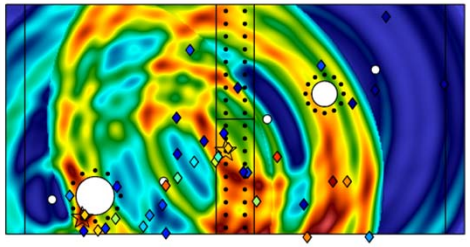


Reconstructed



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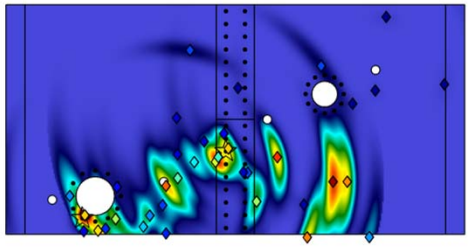

Matched Filtering